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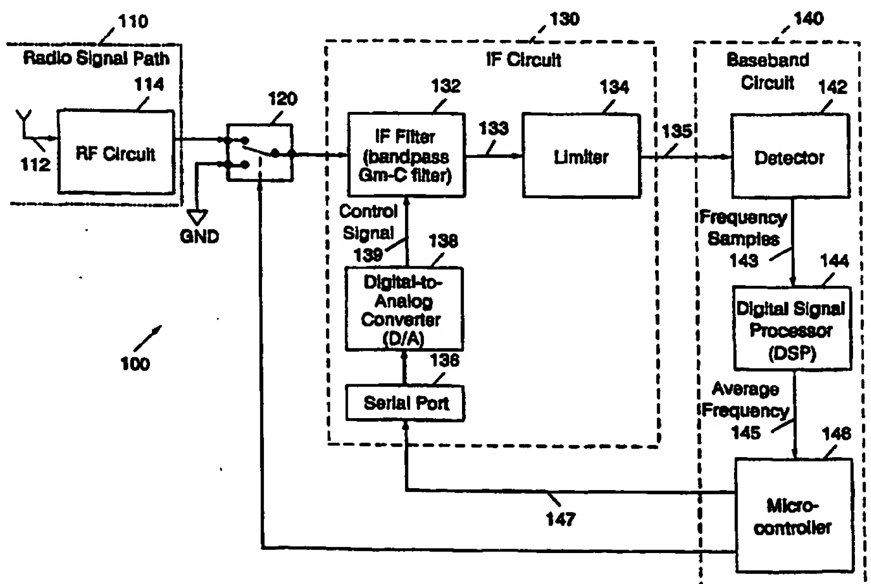
(57) Abstract



A signal having a substantially uniform spectral distribution, e.g., a flat noise signal such as a signal ground, is provided at the input of a bandpass filter such as an IF filter of a receiver circuit, to thereby produce an output signal at the output of the bandpass filter. The output signal is processed in a limiter to produce a limited signal. An average frequency of the limited signal is determined, and the bandpass filter is adjusted based on the determined average frequency. According to one embodiment of the present invention, the bandpass filter comprises a Gm–C filter having a transconductance, and the filter is adjusted by adjusting the transconductance of the Gm–C filter based on the determined average frequency. According to another aspect of the present invention, a desired center frequency for the bandpass filter is identified. A resolution and a desired confidence interval are also identified. The number of samples of the limited signal needed to achieve the identified desired resolution and confidence interval is determined based on the identified desired center frequency. An average frequency is determined by sampling the limited signal to obtain a plurality of samples, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired resolution and confidence level, and determining the average frequency from the plurality of samples. The bandpass filter is adjusted based on the determined average frequency to achieve a center frequency for the bandpass filter that is within a predetermined range with respect to the desired center frequency. Related apparatus are also discussed.

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APPARATUS AND METHODS FOR TUNING BANDPASS FILTERS

Field of the Invention

The present invention relates to electronic circuits and methods of operation thereof, and more particularly, to filter circuits and methods of operation thereof.

Background of the Invention

Traditional superheterodyne radio receiver designs typically use passive intermediate frequency (IF) filters. In many advanced receiver circuit designs, in particular, receiver designs implemented using application specific integrated circuits (ASICs), passive filters have been replaced with active filters that typically are more easily implemented in an ASIC. An active filter structure commonly used in ASIC-based IF circuits is the so-called "Gm-C" filter, which uses transconductance amplifiers and capacitor gyrators to simulate inductors.

The transconductance and capacitance of an integrated circuit Gm-C IF filter can vary with fabrication process conditions. Variations in temperature and power supply voltage can also cause variation of the transfer characteristics of the filter, which may require periodic re-tuning to maintain the passband shape and center frequency. Traditional approaches to tuning Gm-C filters include master-slave tuning techniques, as described in "The Problem of On-Chip Automatic Tuning in Continuous-Time Integrated Filters," Schauman et al., *IEEE Proceedings of ISCAS*,

pp. 106-109, 1989. According to this type of approach, a duplicate (master) filter is formed on the same chip with the IF filter. A reference signal is applied to the duplicate filter to determine its transfer characteristics, and the IF (slave) filter is adjusted accordingly based on the assumption that the characteristics of the master and slave filters are closely matched.

The conventional master/slave tuning technique can be disadvantageous for a number of reasons. To achieve accurate tuning, the components of the master and slave filters generally must be very closely matched. In addition, the additional master filter generally consumes chip area that could be better utilized for other circuitry. Accordingly, there is a need for improved tuning methods and apparatus for tuning receiver filter circuits.

Summary of the Invention

In light of the foregoing, it is an object of the present invention to provide improved methods and apparatus for tuning bandpass filters such as the IF filters employed in a radio communications circuit.

It is another object of the present invention to provide improved methods and apparatus for tuning bandpass filters that can be implemented using fewer components than conventional techniques.

It is yet another object of the present invention to provide improved methods and apparatus for tuning an IF filter in a radio receiver circuit which can be implemented using existing components of the radio receiver circuit.

These and other objects, features and advantages are provided according to the present invention by methods and apparatus in which a bandpass filter, such as an IF filter of a radio receiver circuit, is tuned by providing a signal having a substantially uniform spectral distribution to the input of the filter, determining an average frequency for a limited signal produced by a limiter following the filter, and adjusting the filter based on the determined average frequency. A sampling interval may be determined based on the desired center frequency for the filter and a desired confidence interval, and the limited signal sampled for the desired sampling interval to achieve a plurality of samples from which an average frequency can be determined. The samples may be obtained by processing the limited signal using a detector

included in the receiver circuit. The filter may be Gm-C filter that has a transconductance which is adjustable responsive to a control signal applied to the filter. The control signal may be produced based on the determined average frequency. The filter may be adjusted based on the determined average frequency until a center frequency is achieved which is within a predetermined range with respect to a desired center frequency.

The present invention arises from the realization that in applying a spectrally uniform signal to the input of the bandpass filter, it can be expected that the limited signal produced by the limiter will have a spectrum which has an approximately Gaussian distribution around the center frequency of the bandpass filter. Accordingly, by sampling the limited signal and determining an average frequency thereof, an estimate of the center frequency of the bandpass filter can be obtained with a desired resolution and confidence level. Because the limiter and detector are components normally present in the radio receiver circuit, additional circuitry, such as a master reference filter matched to the bandpass filter, is not required. As the bandpass filter can otherwise be designed such that the passband shape is resistant to variations due to temperature and power supply fluctuations, tuning of the center frequency of the bandpass filter can be performed upon power-up of the receiver circuit.

In particular, according to the present invention, a signal having a substantially uniform spectral distribution is provided at the input of a bandpass filter to thereby produce an output signal at the output of the bandpass filter. The output signal is processed in a limiter to produce a limited signal. An average frequency of the limited signal is determined, and the bandpass filter is adjusted based on the determined average frequency.

According to one embodiment of the present invention, the bandpass filter comprises a Gm-C filter having a transconductance, and the filter is adjusted by adjusting the transconductance of the Gm-C filter based on the determined average frequency.

According to another aspect of the present invention, a desired center frequency for the bandpass filter is identified. A resolution and a desired confidence interval are also identified. The number of samples of the limited signal needed to achieve the identified desired resolution and confidence interval is determined based

on the identified desired center frequency. An average frequency is determined by sampling the limited signal to obtain a plurality of samples, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired resolution and confidence level, and determining the average frequency from the plurality of samples. The bandpass filter is adjusted based on the determined average frequency to achieve a center frequency for the bandpass filter that is within a predetermined range with respect to the desired center frequency. The sampling, determining, and adjusting steps may be repeatedly performed until the average frequency is within a predetermined range with respect to the desired center frequency.

According to another aspect of the present invention, an IF filter of a radio receiver circuit is tuned. The radio receiver circuit includes a limiter connected to an output of the IF filter. A signal having a substantially uniform spectral distribution is provided at an input of the IF filter to thereby produce an output signal at the output of the IF filter. The output signal is processed in the limiter to produce a limited signal. An average frequency of the limited signal is determined, and the IF filter is adjusted based on the determined average frequency. The IF filter may include a Gm-C filter having a transconductance, and adjustment of the filter may comprise adjusting the transconductance of the Gm-C filter according to the determined average frequency.

According to another aspect of the present invention, the IF filter has a passband within a range of frequencies. A noise signal having a substantially uniform spectral distribution within the range of frequencies is provided to the input of the IF filter. For example, the IF filter may be implemented in a circuit having a signal ground, and the radio receiver circuit may be configured to connect the input of the IF filter to one of a radio signal path or the signal ground. The noise signal may be provided by connecting the signal ground to the input of the IF filter. According to another related aspect, connection of the signal ground occurs in response to application of power to the radio receiver circuit. After adjustment of the IF filter, the input of the IF filter may be disconnected from the signal ground and the IF filter connected to a radio signal path.

An apparatus according to an embodiment of the present invention includes a bandpass filter including an input and an output. A signal generator provides a signal having a substantially uniform spectral distribution at the input of the bandpass filter to thereby produce an output signal at the output of the bandpass filter. A limiter is responsive to the bandpass filter and processes the output signal of the bandpass filter to produce a limited signal. Means are provided, responsive to the limiter, for determining an average frequency of the limited signal. Additional means are provided, responsive to the means for determining an average frequency, for adjusting the bandpass filter based on the determined average frequency.

In yet another embodiment according to the present invention, a radio receiver circuit includes an IF filter having an input and an output. Means are provided for providing a signal having a substantially uniform spectral distribution at the input of the IF filter to thereby produce an output signal at the output of the IF filter. A limiter is connected to the output of the IF filter, and limits the output signal to produce a limited signal. Means are responsive to the limiter for determining an average frequency of the limited signal. The means for determining an average frequency may include a detector, a digital signal processor (DSP) and a microcontroller as may be commonly found in a cellular radiotelephone receiver circuit, for example. Additional means are provided, responsive to the means for determining an average frequency, for adjusting the IF filter based on the determined average frequency. For example, the IF filter may include a Gm-C (transconductance) filter which is responsive to a control signal applied thereto, and the means for adjusting the IF filter may comprise means for generating the control signal. A receiver circuit that is tunable using commonly used receiver components is thereby provided.

Brief Description of the Drawings

FIG. 1 is a schematic diagram illustrating a radio receiver circuit according to an embodiment of the present invention.

FIG. 2 is a flowchart illustration of operations for tuning a bandpass filter according to an aspect of the present invention.

FIG. 3 is a flowchart illustration of operations for tuning an intermediate frequency (IF) filter in a radio receiver circuit according to an aspect of the present invention.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. Those skilled in the art will appreciate that the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

For purposes of the discussion herein, descriptions of preferred embodiments utilizing Gm-C (transconductance) bandpass filters are provided. Those skilled in the art will appreciate, however, that the present invention need not be limited to Gm-C filters. It will be understood that in general, bandpass filters that have transfer characteristics that are adjustable may be used with the present invention.

Gm-C filters typically have a transfer characteristic that is adjustable by varying the transconductance of the filter. This may be accomplished in a number of ways, as transconductance amplifiers may have a wide variety of configurations. In a typical transconductance filter, for example, the center frequency of the filter passband is dependent on the ratio of the transconductance and the capacitance of the filter. A well-known technique for adjusting the transconductance of such a transconductance filter is to vary an externally-applied control signal to control a biasing point, as described in "Continuous Time Filters Using Open Loop Tuneable Transconductance Amplifiers," by C. Plett et al., IEEE Proc. ISCAS, pp. 1173-1176 (1986).

The present invention arises from the realization that the signal processing capabilities of limiters and detectors such as those commonly employed in radio receiver circuits may be used to determine transfer characteristics of a bandpass filter such as an IF filter without requiring extensive additional circuitry. A signal having a substantially uniform spectral distribution, e.g., a noise signal that has substantially

flat spectral distribution within the nominal passband of the bandpass filter, is provided to a bandpass filter. According to aspects of the present invention, the output signal produced by the filter is processed in a limiter, and an average frequency is estimated for the limited signal. The estimated average frequency may then be used to adjust a transfer characteristic of the filter, e.g., to adjust the filter's center frequency.

According to a theoretical explanation which in no way limits the scope of the present invention, if a spectrally uniform signal is provided to a bandpass filter, the noise spectrum produced by the filter should approximate the filter's gain response, i.e., the largest amplitude components should occur in a frequency range corresponding to the filter's passband. The noise spectrum produced by the limiter should be similar, i.e., the frequency information should be preserved. Frequency samples can be conveniently obtained from the limited signal, and integrated for a predetermined time to obtain a measure of the filter's average frequency, i.e., an estimate of its center frequency.

The integration time can be found using statistical methods in order to gain a certain confidence that the calculated center frequency is within a desired tolerance of the actual center frequency of the filter. Assuming the limited signal has a Gaussian distribution, a confidence interval for estimating the center frequency of the bandpass filter may be determined. For example, for a 5σ confidence interval, 0.9999994 is the probability that the average frequency determined from the limited signal is the center frequency of the bandpass filter:

$$5\sigma = \frac{f_d}{\sqrt{2}},$$

and thus

$$\sigma = \frac{f_d}{5\sqrt{2}},$$

where f_d is the desired frequency resolution. The average frequency F_c of the limited signal may be computed as:

$$F_c = \frac{1}{N}\sum_{n=1}^{N} F_n,$$

where N represents the number of frequency samples F_n. To achieve a given σ, the number of samples N is given by:

$$N = \left(\frac{BW_{rms}}{2\sigma}\right)^2,$$

where BW_{rms} is the rms bandwidth of the system. The minimum sampling interval T_s needed to produce the number of samples to achieve the desired confidence level is given by:

$$T_s = \frac{N}{f_{\min}},$$

where f_{min} is the lowest center frequency at which the bandpass filter can reside.

For example, for a system with a bandwidth of 30 kHz (BW_{rms} = 21.213 kHz), a desired frequency resolution of 500 Hz, a lowest center freqeuncy f_{min} of 70 kHz and a 5σ confidence level:

$$\sigma = \frac{500}{5\sqrt{2}} = 70.7 \text{ Hz},$$

$$N = \left(\frac{21.213 \times 10^3}{2 \times 70.7}\right)^2 = 22507 \text{ samples, and}$$

$$T_s = \frac{22507}{70kHz} = 0.3125 \text{ seconds.}$$

Accordingly, for this example, if 22507 samples are obtained over a sampling interval of 0.3125 seconds, assuming Gaussian noise at the output of the limiter, the average frequency calculated from the samples will be within ±500Hz of the actual center frequency of the bandpass filter to a probability of approximately 99.99994 %. It

will be understood that if less resolution is desired, the number of samples and the sampling interval can be reduced.

FIG. 1 illustrates a radio receiver circuit 100 for receiving and processing radio signals according to an embodiment of the present invention. The receiver circuit 100 includes a radio signal path 110 including an antenna 112 and a radio frequency (RF) circuit 114. The RF circuit 114 is connected to the input of an intermediate frequency (IF) bandpass filter 132 of an IF circuit 130 via a switch 120. The switch 120 provides means for connecting one of the radio signal path 110 or a signal ground GND (or other signal having a substantially uniform spectral distribution) to the input of the IF filter 132. The IF circuit 130 also includes a limiter 134, which processes signals produced by the IF filter 132 to produce a limited signal 135. The limited signal 135 is passed to a detector 142 of a baseband circuit 140. The baseband circuit 140 also includes a digital signal processor (DSP) 144 and a microcontroller 146 for processing, for example, frequency or phase samples produced by the detector 142. The detector 142 may, for example, generate frequency samples 143 by detecting zero crossings of the limited signal 135, determining time intervals between successive zero crossings, and computing frequency samples based on the determined time intervals.

Those skilled in the art will recognize that the configuration of the radio receiver circuit 100 illustrated in FIG. 1 resembles that of a radio receiver circuit as is typically utilized, for example, in a cellular radiotelephone. According to aspects of the present invention, the IF filter 132 of the IF circuit 130 is adjustable responsive to a control signal 139 produced by a digital-to-analog (D/A) converter 138. The control signal 139 is generated by the D/A converter 138 responsive to a digital output 147 received from the microcontroller 146 via a serial port 136. The digital output 147 is derived from an average frequency 145 for the limited signal 135, as determined by the DSP 144 based on frequency samples 143 produced by the detector 142. Accordingly, standard radio receiver circuit hardware may be used to implement apparatus and methods according to the present invention.

The flowchart illustrations of FIGs. 2 and 3 illustrate, respectively, basic operations for tuning a bandpass filter according to a first embodiment of the present

invention, and detailed operations for tuning an IF bandpass filter in a radio receiver circuit according to second embodiment of the present invention. It will be understood that blocks of the flowchart illustrations, and combinations of blocks in the flowchart illustration, can be implemented by computer program instructions which may be loaded onto a computer or other programmable data processing apparatus to produce a machine such that the instructions which execute on the computer or other programmable data processing apparatus create means for implementing the functions specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus to provide steps for implementing the functions specified in the flowchart block or blocks. Accordingly, blocks of the flowchart illustrations support combinations of means for performing the specified functions and combinations of steps for performing the specified functions. It will also be understood that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, can be implemented by special purpose hardware which performs the specified functions or steps, or combinations of special purpose hardware such as microprocessors, digital signal processing (DSP) chips, application-specific integrated circuits (ASICS) or the like (such as the DSP 144 and the microcontroller 146 of FIG. 1) which execute computer instructions.

Referring to FIG. 2, operations (Block 200 et seq.) for tuning a bandpass filter include providing a signal having a substantially uniform spectral distribution, such as a flat noise signal, to the input of the bandpass filter (Block 210). The output of the bandpass filter is then processed in a limiter to produce a limited signal (Block 220). An average frequency is determined for the limited signal (Block 230). The bandpass filter is then adjusted, e.g., the center frequency of the bandpass filter is adjusted based on the determined average frequency (Block 240). For example, where the bandpass filter is a transconductance filter, the center frequency may be adjusted by adjusting the transconductance of the filter based on the determined average frequency.

Referring now to FIG. 3, operations (Block 300 et seq.) for tuning an IF filter in a radio receiver circuit include powering up the radio receiver circuit (Block 310). In response to power up, a signal ground is connected to the input of the IF filter (Block 320) to provide substantially flat noise thereto. The resulting output of the IF filter is then processed in a limiter (Block 330). The limited signal is sampled for a sampling interval to produce a plurality of frequency samples (Block 340), and an average frequency is determined from the samples (Block 350). If the determined average frequency is not within a predetermined range of the desired center frequency for the IF filter, the center frequency of the IF filter is adjusted, e.g., by adjusting the transconductance of a Gm-C filter, and a new average frequency is determined (Blocks 360, 365, 340, 350). If the determined average frequency is within the predetermined range, the signal ground is then disconnected from the input of the IF filter, and the input of the IF filter is connected to a radio signal path, e.g., to the receiver front end (Blocks 360, 370, 380).

With reference to FIG. 1, to adjust the filter, computing means such as the microcontroller 146 of FIG. 1 may generate a digital output to adjust the center frequency of the bandpass filter based on the determined average frequency. The digital word is in turn converted into the biasing control signal applied to adjust the center frequency of the filter, e.g., by adjusting the filter transconductance. The appropriate digital output may be determined based on a known relationship between the center frequency of the filter and the biasing control signal applied thereto. Typical relationships between biasing signals and transconductance in a transconductance filter are described in the aforementioned article by Plett et al.

It will be appreciated that numerous variations on the above-described operations may be performed that are within the scope of the present invention. For example, instead of performing adjustment of the IF filter in response to powerup, the above-described adjustment procedures may be performed periodically, in response to mode changes in the receiver circuit, and the like. Similarly, in cases where the bandpass (e.g., IF) filter is implemented using a structure other than a Gm-C filter, adjustment of the filter may occur by other means than by changing transconductance.

In the drawings and specification, there have been disclosed typical embodiments of the invention and, although specific terms are employed. they are

used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

THAT WHICH IS CLAIMED IS:

1. A method of tuning a bandpass filter having an input and an output, the method comprising the steps of:

providing a signal having a substantially uniform spectral distribution at the input of the bandpass filter to thereby produce an output signal at the output of the bandpass filter;

determining an average frequency of the output signal; and

adjusting the bandpass filter based on the determined average frequency.

2. A method according to Claim 1, wherein said step of adjusting comprises the step of adjusting the bandpass filter to achieve a desired center frequency.

3. A method according to Claim 1, wherein the bandpass filter comprises a Gm-C filter having a transconductance, and wherein said step of adjusting comprises the step of adjusting the transconductance of the Gm-C filter based on the determined average frequency.

4. A method according to Claim 1 wherein said step of determining said average frequency comprises obtaining zero crossings of said output signal.

5. A method according to Claim 1 wherein said step of determining said average frequency further comprises processing said output signal in a limiter to produce a limited signal.

6. A method according to Claim 5:

wherein said step of determining an average frequency is preceded by the steps of:

identifying a desired center frequency for the bandpass filter;

identifying a desired resolution and a desired confidence interval;

determining a number of samples of the limited signal to achieve the identified desired resolution and confidence interval based on the identified desired center frequency;

wherein said step of determining an average frequency comprises the steps of:

sampling the limited signal to obtain a plurality of samples, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired confidence level; and

determining an average frequency from the plurality of samples; and

wherein said step of adjusting comprises the step of adjusting the bandpass filter based on the determined average frequency to achieve a center frequency for the bandpass filter which is within a predetermined range with respect to the desired center frequency.

7. A method according to Claim 6, wherein said steps of sampling, determining an average frequency, and adjusting the bandpass filter are repeatedly performed until the average frequency is within a predetermined range with respect to the desired center frequency.

8. A method according to Claim 6:

wherein said step of sampling is preceded by the step of determining a sampling interval based on the determined number of samples of the limited signal to achieve the identified resolution and confidence interval; and

wherein said step of sampling comprises the step of sampling the limited signal over the determined sampling interval to obtain the plurality of samples.

9. A method according to Claim 8, wherein said step of determining an average frequency from the plurality of samples comprises the steps of:

detecting a plurality of zero crossings of the limited signal occurring during the sampling interval; and

determining an average frequency for the limited signal from the detected plurality of zero crossings.

10. A method according to Claim 1, wherein the bandpass filter has a passband which falls within a range of frequencies, and wherein said step of providing a signal comprises the step of providing a noise signal having a substantially uniform spectral distribution within said range of frequencies.

11. A method according to Claim 1, wherein the bandpass filter is implemented in a circuit having a signal ground, and wherein said step of providing a signal comprises the step of connecting the signal ground to the input of the bandpass filter.

12. A method of tuning an IF filter of a radio receiver circuit, the method comprising the steps of:

providing a signal having a substantially uniform spectral distribution at an input of the IF filter to thereby produce an output signal at the output of the IF filter;

determining an average frequency of the output signal; and

adjusting the IF filter based on the determined average frequency.

13. A method according to Claim 12, wherein said step of adjusting comprises the step of adjusting the IF filter to achieve a desired center frequency.

14. A method according to Claim 12, wherein the IF filter comprises a Gm-C filter having a transconductance, and wherein said step of adjusting comprises the step of adjusting the transconductance of the Gm-C filter according to the determined average frequency.

15. A method according to Claim 12 wherein said step of determining said average frequency comprises obtaining zero crossings of said output signal.

16. A method according to Claim 12 wherein the radio receiver circuit includes a limiter connected to an output of the IF filter and wherein said step of

determining said average frequency further comprises processing the output signal in the limiter to produce a limited signal.

17. A method according to Claim 16:

wherein said step of determining an average frequency is preceded by the steps of:

identifying a desired center frequency for the IF filter;

identifying a desired resolution and a desired confidence interval;

determining a number of samples of the limited signal to achieve the identified desired resolution and confidence interval based on the identified desired center frequency;

wherein said step determining an average frequency comprises the steps of:

sampling the limited signal to obtain a plurality of samples, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired confidence level; and

determining an average frequency from the plurality of samples; and

wherein said step of adjusting comprises the step of adjusting the IF filter based on the determined average frequency to achieve a center frequency for the IF filter which is within a predetermined range with respect to the desired center frequency.

18. A method according to Claim 17, wherein said steps of sampling, determining an average frequency, and adjusting the IF filter are repeatedly performed until the determined average frequency is within a predetermined range with respect to the desired center frequency.

19. A method according to Claim 17:

wherein said step of sampling is preceded by the step of determining a sampling interval based on the determined number of samples of the limited signal to achieve the identified resolution and confidence interval; and

wherein said step of sampling comprises the step of sampling the limited signal over the determined sampling interval to obtain the plurality of samples.

20. A method according to Claim 17, wherein said step of determining an average frequency from the plurality of samples comprises the steps of:

detecting a plurality of zero crossings of the limited signal occurring during the sampling interval; and

determining an average frequency for the limited signal from the detected plurality of zero crossings.

21. A method according to Claim 12, wherein the IF filter has a passband within a range of frequencies, and wherein said step of providing a signal comprises the step of providing a noise signal having a substantially uniform spectral distribution within said range of frequencies.

22. A method according to Claim 12, wherein the IF filter is implemented in a circuit having a signal ground, wherein the radio receiver circuit is configured to connect the input of the IF filter to one of a radio signal path or the signal ground, and wherein said step of providing a signal comprises the step of connecting the signal ground to the input of the IF filter.

23. A method according to Claim 22:

wherein said step of connecting the signal ground is preceded by the step of applying power to the radio receiver circuit;

wherein said step of connecting the signal ground comprises the step of connecting the signal ground to the input of the IF filter in response to application of power to the radio receiver circuit.

24. A method according to Claim 23, wherein said step of adjusting is followed by the steps of:

disconnecting the input of the IF filter from the signal ground; and

connecting the input of the IF filter to the radio signal path.

25. A method according to Claim 16, wherein the radio receiver circuit further includes a detector, connected to an output of the limiter, which is configured to produce frequency samples of signals produced by the limiter, and wherein said step of determining an average frequency comprises the step of obtaining a frequency sample for the limited signal from the detector.

26. An apparatus, comprising:

a bandpass filter including an input and an output;

a signal generator which provides a signal having a substantially uniform spectral distribution at said input of said bandpass filter to thereby produce an output signal at said output of said bandpass filter;

means for determining an average frequency of the output signal; and

means, responsive to said means for determining an average frequency, for adjusting said bandpass filter based on the determined average frequency.

27. An apparatus according to Claim 26, wherein said means for adjusting comprises means for adjusting said bandpass filter to achieve a desired center frequency for said bandpass filter.

28. An apparatus according to Claim 26, wherein said bandpass filter comprises a Gm-C filter having a transconductance, and wherein said means for adjusting comprises means for adjusting the transconductance of said Gm-C filter based on the determined average frequency.

29. An apparatus according to Claim 28, wherein said transconductance which is adjustable responsive to a control signal applied to said bandpass filter, and wherein said means for adjusting comprises means for generating said control signal based on the determined average frequency.

30. An apparatus according to Claim 26 wherein said means for determining said average frequency comprises means for obtaining zero crossings of said output signal.

31. An apparatus according to Claim 26 further comprising a limiter which processes the output signal of said bandpass filter to produce a limited signal wherein said determining means is responsive to said limiter.

32. An apparatus according to Claim 31, further comprising:

means for identifying a desired center frequency for said bandpass filter;

means for identifying a desired resolution and a desired confidence interval; and

means, responsive to said means for identifying a desired center frequency and to said means for identifying a desired resolution and confidence interval, for determining a number of samples of the limited signal to achieve the identified desired resolution and confidence interval based on the identified desired center frequency; and

wherein said means for determining an average frequency comprises:

means, responsive to said limiter, sampling the limited signal to obtain a plurality of samples from the limited signal, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired confidence level; and

means, responsive to said sampling mean, for determining an average frequency from the plurality of samples; and

wherein said means for adjusting comprises means for adjusting said bandpass filter based on the determined average frequency to achieve a center frequency for said bandpass filter which is within a predetermined range with respect to the desired center frequency.

33. An apparatus according to Claim 32, further comprising means, responsive to said means for identifying a desired center frequency and to said means for identifying a desired resolution and confidence interval, for determining a sampling interval based on the determined number of samples of the limited signal to achieve the identified resolution and confidence interval; and

wherein said sampling means comprises means for sampling the limited signal over the determined sampling interval to obtain the plurality of samples.

34. An apparatus according to Claim 32, wherein said means for determining an average frequency from the plurality of samples comprises:

means, responsive to said limiter, for detecting a plurality of zero crossings of the limited signal occurring during the sampling interval; and

means, responsive to said means for detecting a plurality of zero crossings, for determining an average frequency for the limited signal from the detected plurality of zero crossings.

35. An apparatus according to Claim 26, wherein said bandpass filter has a passband which falls within a range of frequencies, and wherein said means for providing a signal comprises means for providing a noise signal having a substantially uniform spectral distribution within said range of frequencies.

36. An apparatus according to Claim 26, wherein said bandpass filter is implemented in a circuit having a signal ground, and wherein said means for providing a signal comprises means for connecting the signal ground to the input of the bandpass filter.

37. A radio receiver circuit, comprising:

an IF filter having an input and an output;

means for providing a signal having a substantially uniform spectral distribution at an input of the IF filter to thereby produce an output signal at the output of the IF filter;

means for determining an average frequency of the output signal; and

means, responsive to said means for determining an average frequency, for adjusting said IF filter based on the determined average frequency.

38. A circuit according to Claim 37, wherein said means for adjusting comprises means for adjusting said IF filter to achieve a desired center frequency for said IF filter.

39. A circuit according to Claim 37, wherein said IF filter comprises a Gm-C filter having a transconductance, and wherein means for adjusting comprises means for adjusting the transconductance of the Gm-C filter according to the determined average frequency.

40. A circuit according to Claim 39, wherein the transconductance of the Gm-C filter is adjustable responsive to a control signal applied to the Gm-C filter, and wherein said means for adjusting comprises means for producing said control signal based on the determined average frequency.

41. A circuit according to Claim 37 wherein said means for determining said average frequency comprises means for obtaining zero crossings of said output signal.

42. A circuit according to Claim 37 further comprising a limiter which limits the output signal to produce a limited signal wherein said determining means is responsive to said limiter.

43. A circuit according to Claim 42, further comprising:

means for identifying a desired center frequency for the IF filter;

means for identifying a desired resolution and a desired confidence interval;

means, responsive to said means for identifying a desired center frequency and to said means for identifying a desired resolution and confidence interval, for determining a number of samples of the limited signal to achieve the identified desired resolution and confidence interval based on the identified desired center frequency; and

wherein said means for determining an average frequency comprises:

means, responsive to said limiter, for sampling the limited signal to obtain a plurality of samples, the number of the plurality of samples being at least as great as the determined number of samples of the limited signal to achieve the identified desired confidence level; and

means, responsive to said sampling means, for determining an average frequency from the plurality of samples; and

wherein said means for adjusting comprises means for adjusting said IF filter based on the determined average frequency to achieve a center frequency for the IF filter which is within a predetermined range with respect to the desired center frequency.

44. A circuit according to Claim 43, further comprising means for determining a sampling interval based on the determined number of samples of the limited signal to achieve the identified resolution and confidence interval, and wherein said sampling means comprises means for sampling the limited signal over the determined sampling interval to obtain the plurality of samples.

45. A circuit according to Claim 44, wherein means for determining an average frequency from the plurality of samples comprises:

a detector which detects a plurality of zero crossings of the limited signal occurring during the sampling interval; and

means, responsive to said detector, for determining an average frequency for the limited signal from the detected plurality of zero crossings.

46. A circuit according to Claim 37, wherein said IF filter has a passband within a range of frequencies, and wherein said means for providing a signal comprises means for providing a noise signal having a substantially uniform spectral distribution within said range of frequencies.

47. A circuit according to Claim 37, wherein the IF filter is implemented in a circuit having a signal ground, wherein the radio receiver circuit is configured to connect said input of said IF filter to one of a radio signal path or the signal ground, and wherein said means for providing a signal comprises means for connecting the signal ground to the input of the bandpass filter.

48. A circuit according to Claim 47, further comprising means for applying power to the radio receiver circuit, and wherein said means for connecting said input of said IF filter to one of a radio signal path or the signal ground comprises means for connecting the signal ground to the input of the IF filter in response to application of power to said radio receiver circuit.

49. A circuit according to Claim 48, further comprising means for disconnecting the signal ground from the input of the IF filter and for connecting the input of the IF filter to the radio signal path after adjustment of the IF filter.

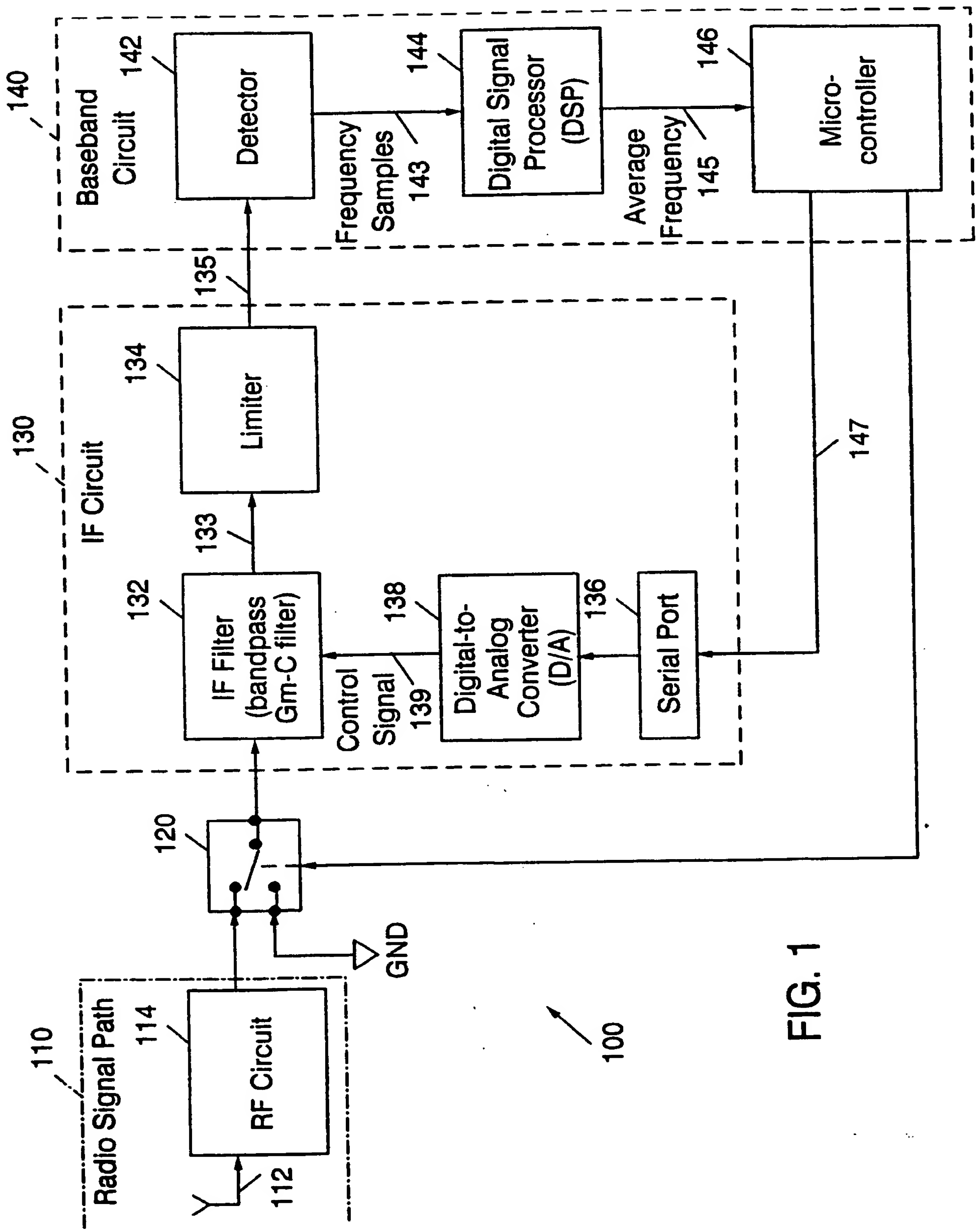
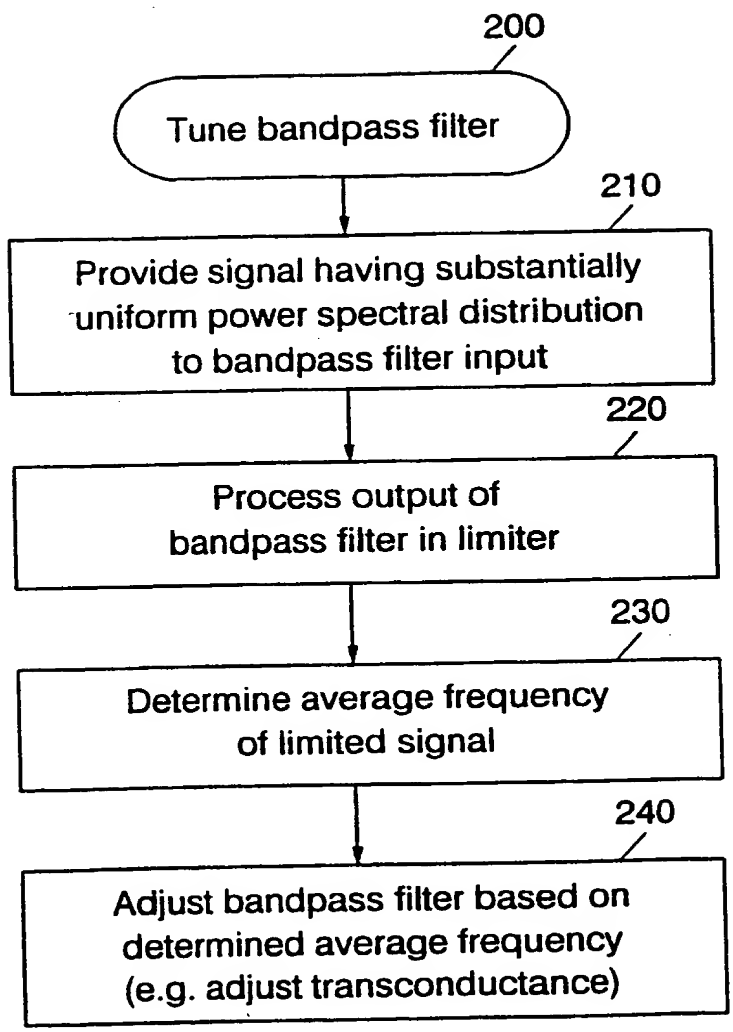

Baseband Circuit
140
Detector
142
Frequency Samples
143
Digital Signal Processor (DSP)
144
Average Frequency
145
Micro-controller
146
147
135
IF Circuit
130
Limiter
134
133
IF Filter (bandpass Gm-C filter)
132
Control Signal
139
Digital-to-Analog Converter (D/A)
138
Serial Port
136
120
GND
Radio Signal Path
110
RF Circuit
114
112
100

FIG. 1

FIG. 2


200
Tune bandpass filter
210
Provide signal having substantially uniform power spectral distribution to bandpass filter input
220
Process output of bandpass filter in limiter
230
Determine average frequency of limited signal
240
Adjust bandpass filter based on determined average frequency (e.g. adjust transconductance)

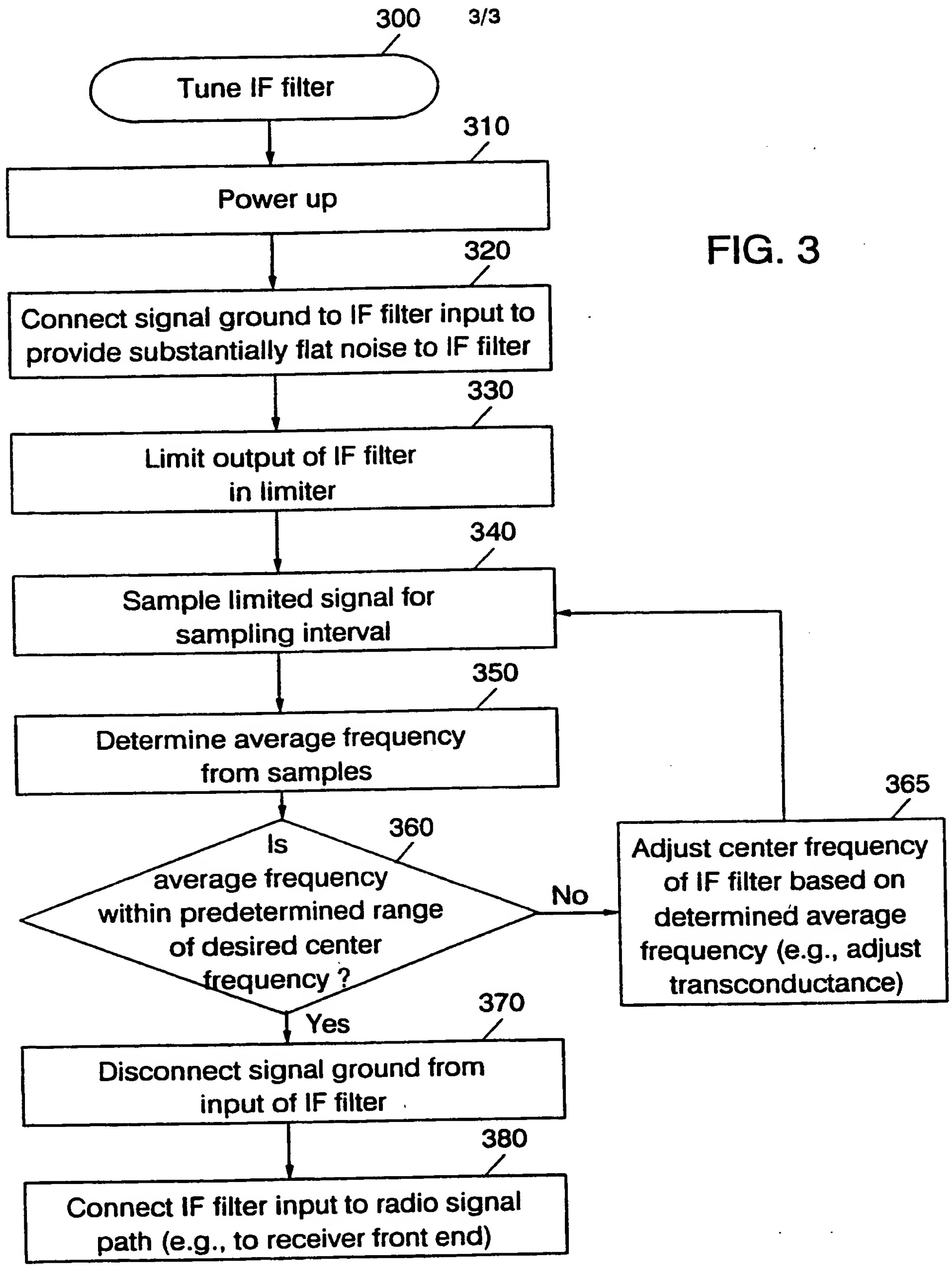

300
Tune IF filter
310
Power up
320
Connect signal ground to IF filter input to provide substantially flat noise to IF filter
330
Limit output of IF filter in limiter
340
Sample limited signal for sampling interval
350
Determine average frequency from samples
360
Is average frequency within predetermined range of desired center frequency ?
No
365
Adjust center frequency of IF filter based on determined average frequency (e.g., adjust transconductance)
Yes
370
Disconnect signal ground from input of IF filter
380
Connect IF filter input to radio signal path (e.g., to receiver front end)

FIG. 3

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/US 99/02424

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H03J3/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H03J G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 003 634 A (MOTOROLA INC) 22 August 1979	1,2,12, 13,26, 27,37,38
A	see page 5, line 33 - page 6, line 7	11,22, 36,47
A	DE 195 40 139 A (ENDRESS HAUSER GMBH CO) 30 April 1997 see abstract; figure 1	1,12,26, 37
A	WO 90 15339 A (INST TEKHN KIB AKADEMII NAUK B) 13 December 1990 see abstract; figure 1	1,12,26, 37
A	EP 0 726 652 A (ALCATEL BELL NV) 14 August 1996 see abstract	3,14,28, 39

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 1999	04/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Peeters, M

INTERNATIONAL SEARCH REPORT

.formation on patent family members

Inte   onal Application No
PCT/US 99/02424

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0003634 A	22-08-1979	US 4232398 A	04-11-1980
		AR 215985 A	15-11-1979
		AU 509265 B	01-05-1980
		AU 4393979 A	16-08-1979
		BR 7900689 A	04-09-1979
		CA 1114022 A	08-12-1981
		DK 51979 A	10-08-1979
		JP 1362828 C	09-02-1987
		JP 54112112 A	01-09-1979
		JP 61031653 B	22-07-1986
DE 19540139 A	30-04-1997	NONE	
WO 9015339 A	13-12-1990	NONE	
EP 0726652 A	14-08-1996	CA 2169235 A	11-08-1996
		US 5661432 A	26-08-1997